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REVIEW: EFFECTS OF INLET CONDITIONS ON DIFFUSER PERFORMANCE

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ABSTRACT

This paper presents the effects of various geometrical as well as fluid dynamics governing parameters on diffusers performance with significance on the inlet conditions for different area ratio in diffusers. The effects of Passage divergence, Length, Area ratio, inlet boundary layer thickness, inlet blockage, Inlet Mach number, Inlet Reynolds number, Turbulence level, Inlet Swirl, Inlet velocity profile, and Distortions have been discussed. The aspects of wall contouring, boundary layer parameters and turbulence model for the improvement of performance and flow characteristics have been considered also. Further various experimental, analytical, and computational studies carried out by various researchers have been reviewed to identify the gaps in the literature.

KEYWORDS: Annular Diffuser, Area Ratio, Reynolds Number, Mach Number & Inlet Swirl

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Original Article

Nomenclature

A	Cross sectional area (m^{2})
AR	Diffuser area ratio (A_2/A_1)
C_p	Pressure recovery coefficient
C_{pi}	Ideal pressure recovery coefficient
η	Diffuser effectiveness
ρ	Density of fluid (kg/m^3)
U	Velocity component in the flow direction (m/s)
θ	Divergence angle (Degree)

INTRODUCTION

The diverging passage used in the industrial applications to attain a reduction in kinetic energy of incoming fluid with a simultaneous rise in the static pressure of flow is termed as ‘Diffuser’. Static pressure occurs when the fluid passes through the duct. The air flow is subjected to greater retardation near the diffuser walls due to flow separation and boundary layer development. Boundary layer development is more pronounced in a diffuser due to the presence of an adverse pressure gradient. Since diffusers normally operate at high Reynolds number, the flow is invariably turbulent. The state and development of the turbulent boundary layer have a considerable influence on the performance of a diffuser. The study of the governing parameters, geometrical parameter, and mechanism of boundary layer generation and their relationship with the diffuser performance are important to optimize the design of diffuser. Flow in the area around the diffuser walls is subjected to an adverse pressure gradient due to the formation and development of the boundary layer. The diffuser has a wide range of practical applications and used in ramjets, inlet portions of jet engines, combustion chambers, axial flow compressors, and centrifugal compressors, etc.

Pressure rise due to a decrease in the kinetic energy is a function of the change in the area of the diverging section for the one-dimensional incompressible flow of a non-viscous fluid. In the diffuser, the real fluid retards progressively due to the presence of an adverse pressure gradient and boundary layer growth adjacent to the solid wall and with the diffusions, it thickens rapidly.

Geometrical parameters such as length, aspect ratio, divergence angle, area ratio etc. are essential to determine the optimum geometry of the diffuser. The fluid dynamic parameters such as inlet velocity, blockage factor, velocity profile, turbulence level, Reynolds number, Mach number, flow pulsation, and inlet swirl helps to understand the core flow phenomenon and diffuser performance. The annular type diffuser exists particularly in turbo machines, where fluid may have to flow over and around a hub, or a central shaft together with its bearings and supports. The research of extensive nature continues in progress since previous decades by various researchers and giant manufacturers of the field to carry out or define its optimum geometrical characteristics.

It is well demonstrated that diffuser of annular type are complex in nature and the parameter like inner wall of the diffuser leads to enhancement in its complexity. Flow through annular diffusers is characterized by a rapid growth of the boundary layer, leading to various degrees of irregularity in the flow pattern, non-uniformity of the velocity profile, total pressure loss, instability and recirculation of the flow. Experimental investigation helps the researchers to minimize the undesirable effects, thereby optimizing the retrieval of the static pressure rise. The experimental investigation, combined with the empirical relations or analytical studies helps in improving the diffuser performance. Figure-1 shows the frequency of the research article published in the last seven decades on the diffuser.

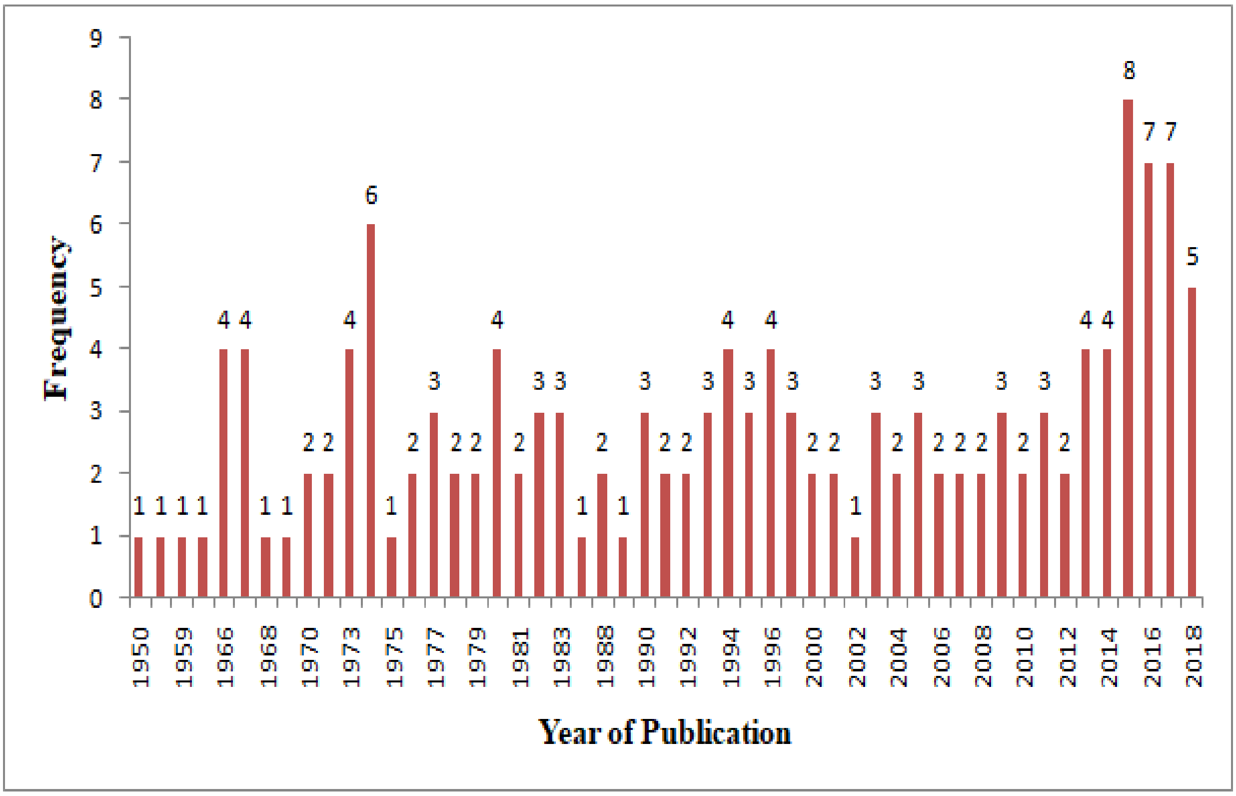

Figure 1: Frequency of Article on the Diffuser

DIFFUSER PERFORMANCE PARAMETER

The diffuser performance is evaluated in terms of two performance parameters, and their variations are presented is given below:

Pressure recovery coefficient

$$C_p = \frac{P_2 - P_1}{\frac{1}{2}\rho u^2} \tag{1}$$

Subscript 1 and 2 are used for inlet and outlet, respectively.

Overall diffuser effectiveness

$$\eta = \frac{C_p}{C_{pi}} \tag{2}$$

Where $C_{pi} = 1 - \frac{1}{AR^2}$

STUDIES OF GEOMETRIC PARAMETERS

Passage Divergence, Length and Area ratio

The performance of diffuser depends upon the geometrical parameter (i.e., area ratio, divergence angle, and length of diffuser), which is shown in figure-2.

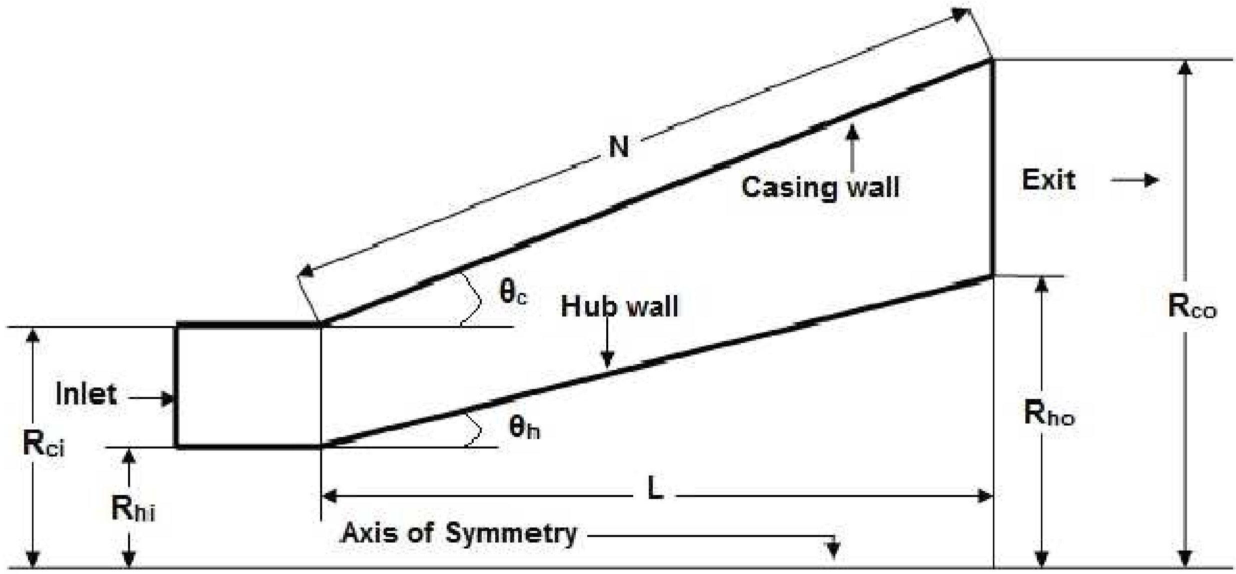

Figure 2: Annular diffuser Geometrical Parameters [8]

Azad[10] and Duggins [23] worked on the conical diffuser had an inlet diameter of 0.1016 m, an area ratio 4 to 6, with the total divergence angle of 8° had shown that Measurements up to the fourth-order of moments in a conical diffuser. Within the AR range considered, the pressure recovery reaches a maximum at an area ratio of approximately 6:1, and remains constant with further increase in AR. Walkeret al. [91] reported the improvement in static pressure recovery and total pressure reduction in hybrid diffuser as compared with a conventional diffuser by increasing area ratio within the same axial length. Sparrow et al. [81] and Salim [69] studied the flow separation and diffuser performance in a diverging conical duct with different divergence angles. It has been seen that separation occurred on the 7° expansion angle of

diffuser having the Reynolds number less 2000. The length of flow separation diminishes with an increase in the Reynolds number. Senoo et al. [72] analyze the effect of swirl on pressure recovery in the five conical diffusers with different divergence angles. For a given exit/Inlet area ratio, the maximum pressure recovery was achieved in an 8 deg divergence angles of the diffuser. The diffuser effectiveness with the cone angle plotted in figure 3 shows that the maximum performance occurs when the cone angle is in the range of 5°-35° with the various area ratios.

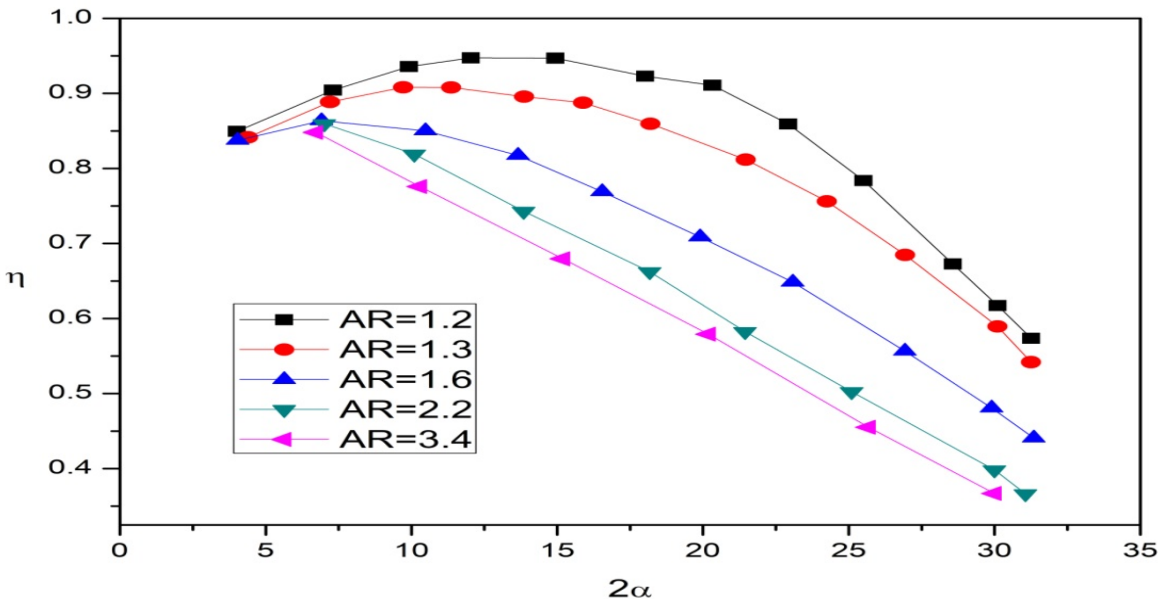

Figure 3: Relationship between diffuser Effectiveness and Cone Angle

Kibicho and Sayers [39] reported on the separation of flow along the diffuser wall due to the adverse pressure gradient in the two-dimensional diffuser geometry. By increasing the velocity from 9-10 m/s to 18-20 m/s, the static pressure recovery increased by 9% for the given geometry of 30° diffuser. Abdalla et al. [1] investigated the conical diffusers of various divergence angles ranged from 4 to 40 degrees keeping. The axial length of the diffusers equal to 4.3 times the inlet diameter. The largest improvement of the performance was seen in wide-angle diffusers as compare to conical diffusers having small divergence angles. Waitman et al. [90] studied the subsonic two-dimensional plane-wall flow characteristics in diffusers. Static-pressure recovery is the function of Inlet-boundary layer conditions. As the inlet boundary layer is thickened, then reductions in pressure recovery take place [9]. Pramod et al. [65] worked on the annular diffuser with a divergence angle of 13 degrees by stabilizing the length of diffusion. At the inlet, the velocity is varied from 80 m/s to 160 m/s in the steps of 40 m/s. Due to the high rate of diffusion, pressure recovery increases with an increase in area ratio and loss in pressure recovery also increases. Johnston [35] reported on annular diffusers having an area ratio of 3.2 and divergence angle range from 6.5° to 15°. As the divergence angle increased the efficiency become decrease due to the inlet conditions is non-uniform. Shimizu et al. [75] analyzed the straight conical diffuser performance with divergence angle range from 6° to 18° and an area ratio of the diffuser from 2.1 to 15.9. The good performance achieved in the conical diffuser with asymmetrical velocity profile at the inlet and one-directional swirling component exists [38]. Cerantola and Birk [13-14] predicted the effectiveness of short annular diffuser with and without swirl having an area ratio 1.61 to 2.73.The highest diffuser performance achieved with a 10-degree inlet swirl for the area ratio 1.91. Ganesan [27] reported on straight core annular diffuser to predict the velocity profile, momentum thickness, pressure recovery, effectiveness, and

boundary layer development in diffusers. The predicted pressure recovery coefficient shows a good agreement with the experimental result up to the cone angle of 15°.Kurokawa et al. [46] studied the effect of J-groove in a conical diffuser with a divergence angle of 20 degrees. The velocity distribution result shows an about 40% reduction of swirl intensity by the installation of the J-groove. Figure- 4 shows that the effect of area ratio on the static pressure recovery coefficient C_p.

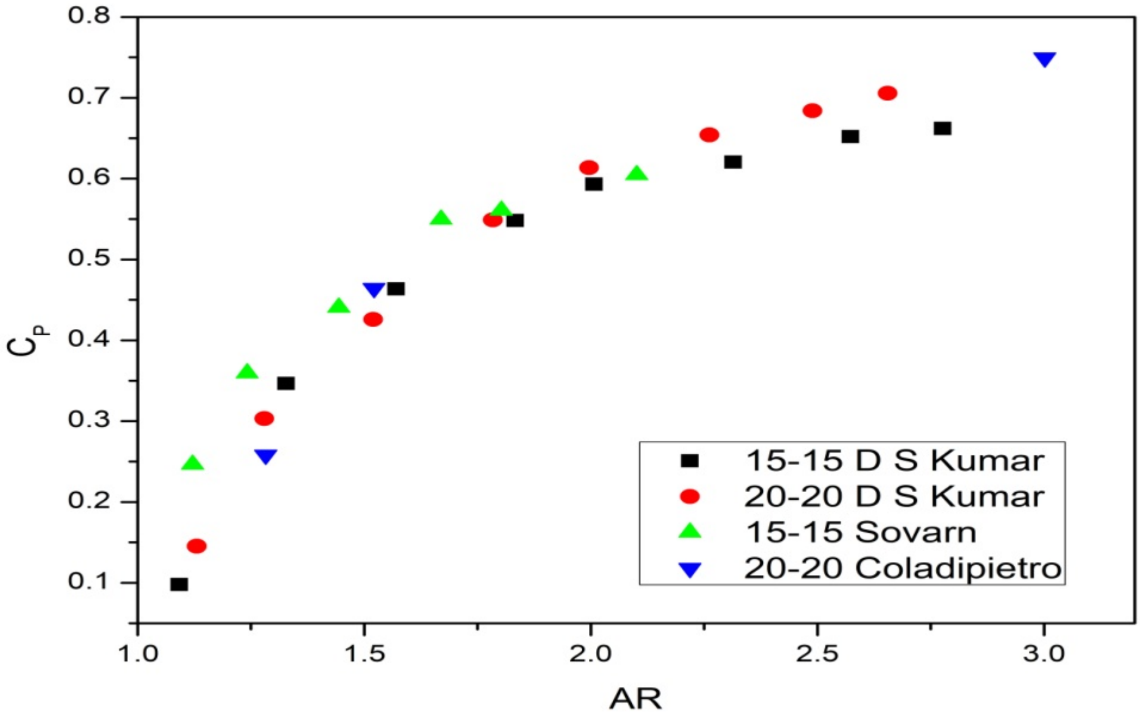

Figure 4: Static Pressure Recovery Coefficient with Area Ratio [44]

Inlet Profile and Distortions

The inlet profile is due to the growth of the turbulent boundary layer on the diffuser wall. The various method was used to control the inlet profile can be achieved by providing trip wires or center bodies or a sufficient length of constant area pipe a head of the diffuser. The basic parameters which define the inlet mean velocity profile include the approach length of the upstream pipe, the displacement, and the momentum thicknesses and profile 'peakiness' etc. Inlet profile Peakiness is defined as the ratio of the maximum to the mean velocity. The performance of a diffuser deteriorates with an increase in the boundary layer thickness as found experimentally by many researchers. The manner in which the inlet boundary layer has been thickened is equally important as the thickness of the boundary layer in determining diffuser performance. Marsan et al. [53] and Mehta [55] studied the performance of diffusers depends upon the inlet velocity profile of the fluid flow. The undisturbed profile in which fluid flow on the hub is stable while in case of disturbed profile flow is separated from the hub and low shear stress on the wall. The static pressure recovery and flow characteristics more influence on the inlet velocity profile in the annular diffuser [92]. Sajben et al. [68] studied the seven different inlet velocity profiles on the conical diffuser at low subsonic speed. The performance is predicted based on static pressure recovery and exit velocity distribution. Padilla et al. [63] reported on the three annular diffusers with different expansions ratio with four inlet conditions. Distortion of inlet velocity profile in a two-dimensional diffuser has considerable influence on its performance. The static pressure recovery achieved about 80 percent first-half length of diffuser [58]. The annular diffuser with an area ratio ranges

from 1.9:1 to 3.2:1, and different levels of Mach number. It is predicted that about 85 percent pressure recovery obtained in one-third of diffuser length [3, 4]. Lo et al. [50] investigated the effect of the center body on the conical diffuser with the annular inlet. Conada blowing method was used to mitigate the central separation zone and high momentum flow of fluid toward the center. Reneau et al. [67] performance of diffuser is much more affected by inlet conditions as compared to the flow regime. The integral turbulent boundary layer method was used to predict the pressure recovery in the two-dimensional diffuser there is a boundary layer not too thick. Al-Mudhafar et al. [5] predicted the pressure recovery in the two-dimensional diffuser. It has been observed that as inlet velocity profile distorted the pressure recovery of diffuser decreases. Stevens [82], Stevens and Fry [83] analyzed the performance of annular diffuser it shows that the efficiency of diffuser deteriorates with the increase of outer wall momentum thickness. A reasonable compromise has been obtained between experimental and theoretical results for static pressure distribution, boundary layer growth, and separation for flow in the conical and annular diffuser.

Inlet Blockage Factor

Inlet boundary layer affects the performance of a diffuser which is usually investigated in terms of the blockage factor B and the effective area-fraction E. These terms are defined as

$$\mathrm{B} = 1 - \mathrm{E} = \frac{1}{\mathrm{A}}\int\left(1 - \frac{U}{U_m}\right)da \quad (3)$$

Where A is the area of flow, U is the local velocity, and U_m is the maximum velocity.

$$E = \frac{1}{A}\int\frac{u}{Um}da \quad (4)$$

Kline [40] and Kline et al. [41] found out the effect of inlet blockage, inlet turbulence intensity, and inlet shape factor on the performance of conical diffuser. The pressure recovery coefficient increased due to increases in the intensity of turbulence. McMillan and Johnston [54] studied the performance of rectangular diffuser with a low aspect ratio, considering the effect of fully developed, incompressible, and turbulent flow. In low aspect ratio, diffuser pressure recovery and effectiveness very less in comparison to high aspect ratio diffuser. Overall, 15 percent of total pressure loss is in low aspect ratio diffuser to pressure loss in channel diffuser, which is in equal of length. Senoo and Nishi [71] analyzed the separation of flow in a conical diffuser using a boundary layer method. From the results, it was seen that more stable flow due to the large size of blockage very little flow separate from the boundaries. The relation is developed between shape factor and blockage factor for the separation limit of flow in the diffuser. The pressure recovery calculated from the experimental data very well satisfactory except for the separation point.

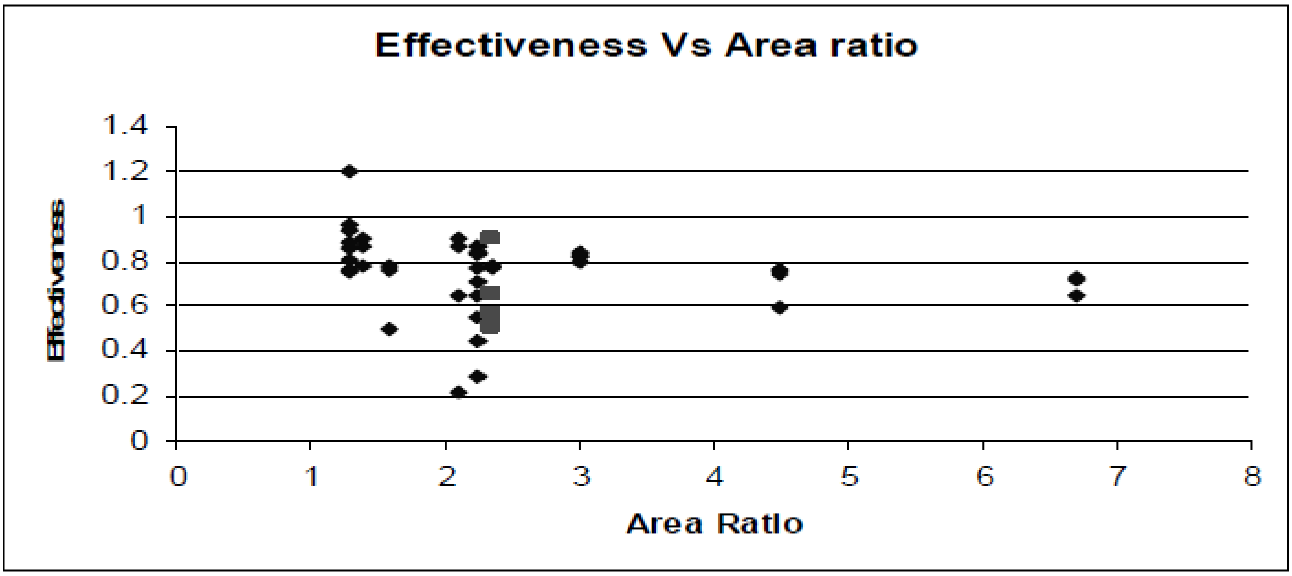

Figure 5: Graph Plotted between diffuser Effectiveness and Area Ratio [32]

Figure-5 shows the effectiveness of an annular diffuser which depends upon the geometry, inlet swirl angle, and inlet aerodynamic blockage. The aerodynamic blockage is a very important variable to find the effectiveness of an annular diffuser. Tyler and Williamson [85-86] also showed experimentally that a continued increase in the inlet blockage resulted in the effectiveness rising again and eventually exceeding unity. The inlet distortion became severe enough and the beneficial effect of mixing prevailed over the harmful effect of increased blockage. Experiments by Reneau et al. [67] and the analysis presented by Sovran [79], Sovran and Cocanower [80] have indicated that diffusers of optimum geometry were only slightly affected by inlet distortion. Livesey and Odukewe [49], Sharan [73] studied the conical diffuser with the aerodynamic blockage in as a function of approach length. The initial pressure recovery reduces and then increases as the length increases due to boundary layer growth. Noui et al. [61] found out the complicated effect of the different blockages as seen by the flow within the diffuser. Different screen configuration method was used to achieve the uniformity of flow at the outlet, velocity distributions, and pressure profiles measured in the 30° wide-angle diffusers with an area ratio 7. Japikse [32] reported on the effectiveness of diffuser, which is developed a correlation equation for the annular diffuser. The effects of aerodynamic blockage and stall process, which is reflected on velocity profiles and overall performance of diffusers.

Inlet Reynolds Number and Mach Number

Kibichov and Sayers [39], Moller [57], Nordin et al. [59] and Adenubi [2] studied the effect of Reynolds number on static pressure recovery in the conical and radial diffuser, as the divergence angle was increased by some amount in proportional to static pressure recovery increased. The higher percentage of pressure recovery is achieved by increases the Reynolds number. If the Reynolds numbers below than 10^5 for the radial diffuser, the pressure recovery decreased rapidly. Nordin et al. [60] simulated the performance of 3-D turning diffuser with various inlet conditions and geometrical parameters. To analyze the characteristics of flow in 3-D turning diffusers utilizing varying Re_{in}= 5.79 x 10^4 - 1.78 x 10^5. The functions of inlet boundary conditions, the performance correlations are successfully developed via ACFD with approximately 7% experiment deviation.

Table 1: Geometry of Diffusers, Divergence Angle, Area Ratio, Reynolds Number and Mach Number

References	Diffuser Type	Divergence Angle	Area Ratio	Reynolds Number	Mach Number	Finding
Moller,1966 [57]	Conical	7°	5	$2x10^5$ to $5x10^5$	-	Pressure recovery of radial and conical diffuser decreases with decreasing Reynolds numbers
Adenubi,1976 [2]	Annular	5°,10°, and 15°	1.47,2.00 and 2.60	$1.2x10^5$ to $6.0x10^5$	0.03 to 0.14	The flow regime characteristics and effect of diffuser performance parameters
Van et al.,1966 [87]	Conical	4°,8°15.8°, and 31.2°	2.43,4.48 and 8.27	-	0.25,0.55 and 0.70	Mach number effect on the performance of the diffuser
Adkins,1975 [4]	Annular	30°	1.9:1 to3.2:1	10^5	0.23 and 0.6	To find out the C_{TL} and C_{PR} with respect to area ratio
Al-Mudhafar et al.,1982 [5]	Rectangular	12°	1.855	80000 to 320000	0.1 to 0.6	Find out the performance of diffuser with respect to the inlet velocity profile
Deanet al.,1969[20]	Straight channel	8° to 16°	AS=0.25 to 1.0	10^6	0.2 to 1.0	shows the importance of Mach number, inlet blockage and geometric parameter of the diffuser

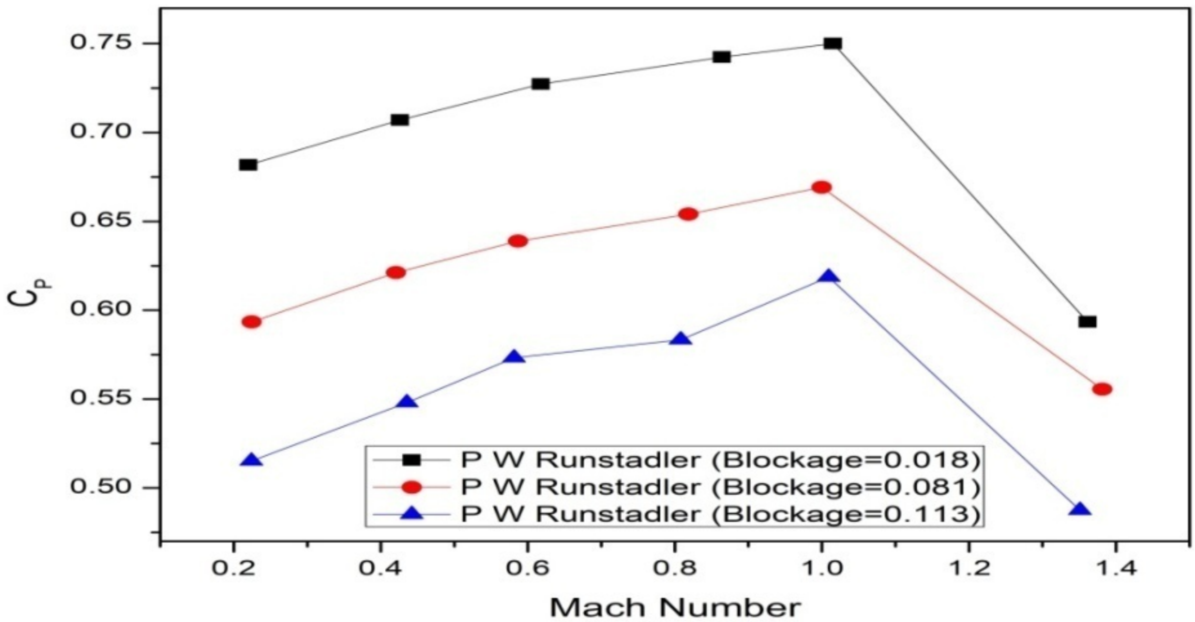

Figure 6: Static Pressure Recovery with Mach Number [20]

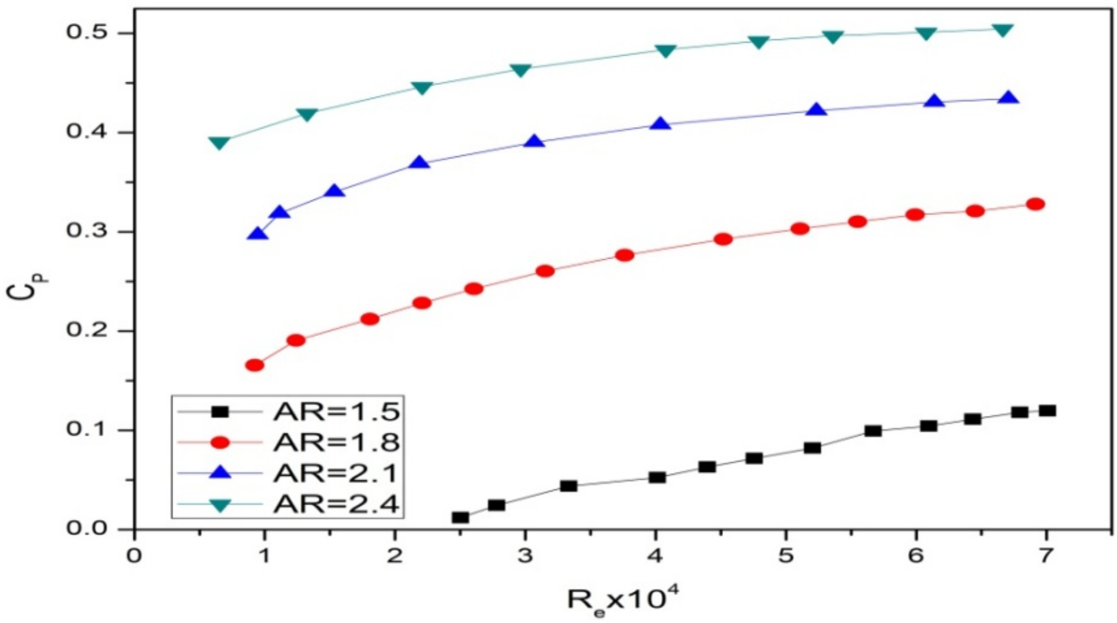

Figure 7: Static Pressure Recovery with Reynolds Number [54]

Figure-6 shows the variation of the diffuser performance with the inlet Mach number to correlate with static pressure recovery for incompressible flow. Figure-7 shows the static pressure recovery of diffusers increased by increasing the Reynolds number. Gartner and Amitay [28] analyzed the effectiveness of several passive and active actuators of the rectangular diffuser. The efficacy of height, the array of passive vortex generator attached to the upstream of ramp and vortex generator spacing on these parameter studies were conducted. Due to this at the AIP pressure recovery improved from 78.5% to 85.5%.The entrance of the diffuser shock wave has occurred as a result of the Mach number, and total pressure reduces quickly as correspond to the static pressure and static temperature increase rapidly [93].Van et al. [87] Analyzed the performance is varied with the value of Mach number for incompressible flow in the conical diffuser. The performance of diffuser is independent of divergence angle lying below the line first appreciable stall at given Mach number and area ratio of the diffuser geometry. Dean et al. [20] and Little et al. [48] studied the importance of geometrical parameter, Mach number, Inlet blockage, and aspect ratio of the diffuser. The performance (i.e., total-pressure-loss coefficient and effectiveness) of the diffuser is more influenced by the boundary layer thickness and diffuser divergence angle. The performance of diffuser was obtained reduced rapidly with increasing the value of these variables.

Inlet Turbulence Level

The turbulence intensity *Tu* is most frequently defined as an RMS value

$$Tu = \frac{[1/3(u'^2+v'^2+w'^2)]1/2}{U} \tag{5}$$

Where *u, v* and *w* are turbulent velocities in *x, y* and *z* directions

Obi et al. [62] reported on turbulent separating flow in an asymmetric plane diffuser with turbulence models. LDV measurements of the turbulent separating flow in an asymmetric diffuser have been performed. The second-moment closure fails in providing the correct level of the shear stress component upstream of the flow separation [12]. Redha et al. [66] stated on diffusers to reduce the noise level and head loss in the largest wind tunnel configuration. To predict the reduction of noise is analyzed by turbulence kinetic energy in the jet. The same diffuser greatly decreases the turbulence as

showed in the results, hence the noise is reduced. Stevens and Williams [84] conducted studies on characteristics of the outlet flow, pressure recovery, and the total pressure loss. The mean velocity profile measurements have been made at the number of stations along the length of the diffusers. Results show that gain in pressure recovery, the stability of the outlet flow and little gain in total pressure loss. Wall pressure measurements, mean velocity, and turbulence profiles showed that the flow near the end of the channel was fully developed. Upstream velocity profiles and downstream of the diffuser was showed a large discrepancy in the mass flow rate of fluid [15]. Cho and Fletcher [15] studied the conical diffuser with a divergence angle 8° to 20° for the prediction of complex turbulent flows. Two turbulence models were used to predict the velocity profile accurately. ASM Turbulence model predicted accurate results over the k-ε turbulence models when compared with the experimental value.

Inlet Swirl

Swirling flow at the inlet of diffuser means that the tangential component of velocity is present. The effect has been considered for conical and annular diffusers, even though it is important two-dimensional diffusers as employed in various pumps and compressors. The common way of representing the swirl is in terms of the angle of swirl at the inlet.

Swirl flow has been generated by guide vanes located at the diffuser entry or by the rotation of a body placed within it. Clausen et al. [16], Ji-jun et al. [34] and Dellenback et al.[21] Studied the conical diffuser with divergence angle range 12 to 20 degree having turbulent swirling flow with different swirl number, flow separation are predicted by two-layer wall function with algebraic Reynolds stress and k-ε turbulence model. Swirl tends to recirculate the flow, which increases the velocity near the boundary edge due to that very little flow separate from the wall [59-60, 64]. Singh et al. [77-78] investigated the performance of annular diffuser with different inlet swirl angle having the same equivalent cone angle (2θ = 15°). The best performance of the diffuser has been achieved on the introduction of swirl, the optimum value of swirl lies between 20° and 30°. Separation occurs on the hub wall and degrades the performance if further increases the value of swirl. Lohman et al.[51] studied the performance of an annular diffuser with the conical wall of various lengths, area ratio and divergence angle experimentally evaluated over the range of swirl angle up to 48 degrees. The separation occurred in the inner wall of diffuser it can be encountered by increasing swirl angle at lower area ratio.

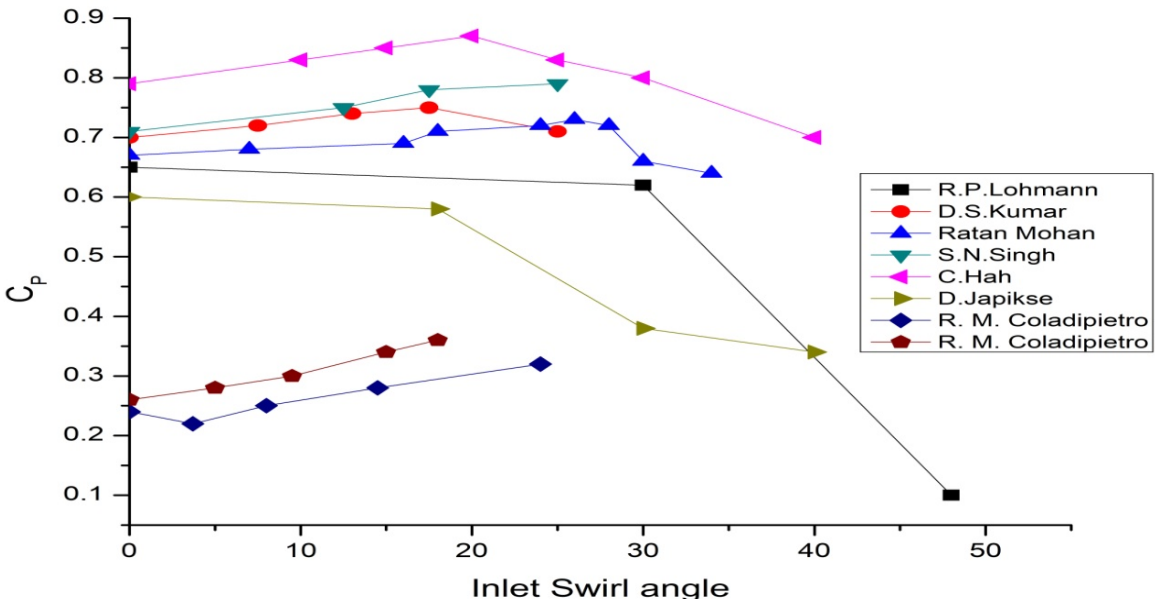

Figure 8: Straight Annular diffuser Performance with a Swirl at Various AR [32]

Figure-8 indicates that optimum swirl angle for pressure recovery with different test of diffusers by plotting its performance against the degree of swirl. As the inlet swirl angle increased from 30°, the velocity profile starts to be distorted and declined the pressure recovery of the diffuser. Mohan et al.[56] three straight-walled annular diffuser with an equivalent half cone angle of 12.5°,15°, and 17.5° have been analyzed. Inlet swirls up to a particular level improve pressure recoveries but after that has a detrimental effect. The overall static pressure recovery increased around 40% for swirl flow at inlet either clockwise or anticlockwise direction of swirl. The uniform flow distribution at the inlet and the exit plane is more uniform for the clockwise swirl in comparison to the anti-clockwise swirl. Singh et al. [77] found the performance of wide-angled annular diffusers with equal hub and casing angle. The effect of inlet swirl evaluated in terms of diffuser performance parameters and flow developments. Swirl enhances the pressure recovery and helps in suppressing the flow separation on the casing for wide-angled diffusers. The reduction in effective diffuser length is achieved by increases the value of the inlet swirl angle. Kumar et al. [45] the effect of various inlet swirl angles between 0° and 25° has been evaluated in the annular diffuser. It shows that swirl improves the performance of the system in the term of pressure recovery coefficient. Kochevsky [42] studied the rotation of hub with swirling flow in an annular diffuser installed at the exit of the hydraulic machine. The intensity of swirl flow is increased due to the hub rotation in the direction of flow. The rotation of the hub in the opposite direction then swirls flow intensity decreased. Kumar [43], Kumar and Kumar [44] concluded on the annular diffusers having subsonic turbulent swirling flows in diverging casing and diverging hub geometries. The overall pressure recovery is increased due to the presence of inlet swirl, increasing more efficiently for stalled diffusers as compared to behave diffuser well. The pressure recovery within a diffuser increases as the flow proceeds the drop of pressure recovery increase as the distance from the inlet increase correspondingly. Ghose et al. [29] studied the effect of dome shape on pressure distribution and flow pattern along the casing wall over the different levels of swirl number. Effectiveness and pressure recovery achieved by considering the different levels of swirl angle in the range of 25-30 degrees. Kanemoto et al. [36] studied the thin and thick boundary layer with swirl flow in the annular diffuser. The best pressure recovery is about 24 degrees at the best convergent angle of the hub while the flow is no whirl component at the inlet.It is possible to prevent the flow separation by giving an adequate whirl flow component at the inlet. Hah [31], Crane and Burley [19] reported on the three diffusers for predicting the turbulent flow characteristics with considering the effect of inlet swirl and distortion effects. The turbulence closure modeling is appropriately included in the outcome of streamline curvature. Fox and Mcdonald [25-26] predicted the performance and effectiveness of twenty-four different conical diffusers, and divergence angles range from 4.0 to 32° and with area ratios range from 1.30 to 8.23 were tested. The effect of inlet swirl for a given diffuser correlated with the flow regime present for axial inlet flow. Swirl improves the overall performance of a complete flow system. Japikse and Pampreen [33] found out the performance of annular diffuser with different parameter, i.e., Reynolds number, Mach number, inlet blockage level, and inlet swirl. The maximum pressure recovery in exhaust diffuser achieved at 45-degree inlet swirl with a double collector. Single exit port in exhaust diffuser shows a poor performance at high Mach number. Coladipietro [17] reported on the short diffusers, the variation of pressure recovery with blockage was similar to the channel, and conical diffusers; that is the pressure recovery decreased with increasing blockage. However, for the long diffusers, the higher performance was observed at, the higher blockage levels.

Analytical and Computational Studies

Armfield et al. [6] reported the turbulent swirl flow through the conical diffuser with a divergence angle of 12°-20°.

Swirl numbers were used to improve recovery of pressure predicted by two-layer wall function using k-ε and algebraic Reynolds stress turbulence model. To assess the accurate location, level, and variation of swirl flow in the axial direction in turbulence quantity evaluated with the help of a two-layer wall function rather than a single layer method. Dominy et al.[22] finite volume technique has been adopted to predict the flow using the standard k–ε turbulence model. Swirl is an effect on characteristics of flow as pass thorough diffusing duct and redistribution of loss as present near the wall. Arora and Pathak[7, 8], Singh and Arora [76] reported on the annular diffuser with area ratio 2 to 4 having different inlet velocity profile obtained experimentally computed with CFD. RNG k- ε model has been employed to validate with experimental results for predicting the performance of axial annular diffuser. Gorman et al. [30] five turbulence models were evaluated using the experimental result with swirl flow in numerous engineering practices. Turbulence model is κ–ε, RNG κ–ε, κ–ω, SST, LES model. Among the RNS based two-equation model, the SST κ–ω model proved to be the most effective. Heat transfer applications are that the SST κ–ω predictions of the velocities near the wall of the apparatus were especially excellent compared with the predictions of the other models. Barbosa et al. [11] mathematical model was developed to work on the behavior of internal velocity for three conical diffusers. The velocity gradient is positive; the model matches with the experimental data within the diffuser area, with maximum velocity value. At large angles of the diffuser, the velocity gradient is negative, and experimental data are incompatible with the theoretical results, due to the separation of flow and viscous effects. El-Askary et al. [24] numerically validate the two-phase flow by the use of Eulerian-Lagrangian approaches with the help of Chen-Kim k-ε turbulence model. The two techniques have been used to solve the problem i.e. continuous phase and dispersed phase. Vlahostergios and Yakinthos[89] reported on the two different Mach numbers in a converging-diverging diffuser with the transonic flow. To predict the nature of flow in a diffuser gives quite exact results with the use of more complicated turbulence models. Selvakarthick et al. [70] stated the highest possible static pressure recovery with the shortest possible length in the Aero-gas turbine engine with dump diffuser design. Lipeng et al. [47] analyzed the turbulent flow in the rectangular asymmetric diffuser by CFD with seven turbulence model. RSM turbulence model gives better results than other turbulence models for assessment of static pressure, velocity, vortices, and flow characteristics. Some discrepancies still observed in the DNS, and LES results as compared to experimental results. Vassiliev et al. [88] several turbulence models have been assessed, standard k-ε models, realizable k-ε models, including one-equation models and with wall function. The realizable k-ε model with two-zonal near-wall treatment has been the most suitable one for the accurate simulation of diffuser flows among these models. Sheeba and Ganesan [74] studied the characteristics of an annular diffuser for various flow give good predictions using the k-ε model than a satisfactory physical model. The flow were disturbed and spread by lack of field in the diffuser due to the strut. The flow was disturbed and spread in the diffuser due to the strut. The development of pressure recovery without strut in the diffuser was more than the pressure recovery with the struts. Yongsen et al. [94] studied the conical diffuser having an area ratio of 4 and divergence angle 8°with Reynolds numbers ranging between 1.16x 10^5-2.93x$10^5$and simulated by k-ε turbulence model. The assessment of flow characteristics in the diffuser, turbulence energy, and mean flow velocity is predicted using the BFC technique inside conical diffusers. Constantinescu et al. [18] studied the main feature of three-dimensional large eddy simulation two-phase flow code using unstructured meshes to simulate non-reacting and reacting flow through realistic combustor geometries. These simulations show the superior predictive capabilities of the LES technique as compared to RANS based solver for predicting flow, turbulent mixing, and combustion phenomenon in combustors. Mansour et al. [52]

and Kanemoto et al. [37] analyzed the dependence of the eddy-viscosity damping function on the Reynolds number and the distance from the wall. The analytical results explain well with the main flow behavior, and the axial flow comes to increase near the hub side with a spread of the free vortex flow region.

GAPS IN LITERATURE

- The performance of diffuser needs to be explored with inlet velocity profile distortion, swirl and various geometrical parameters.
- Limited Research work on the Annular Diffuser with variable inlet conditions.
- The experimental data about the pressure recovery coefficient and the total pressure loss for a wide range of geometrical parameters is scanty.
- Swirl flow needs to be investigated experimentally with inlet velocity profile and inlet blockage factor along with dynamical diffuser parameters.

CONCLUSIONS

The flow behavior of diffusers has been carried out to re-examine different aspects to present them systematically and in a proper perspective. From this study, it is apparent that defining the optimum parameters such as the geometry, area ratio, divergence, inlet profile, distortion, inlet Reynolds number, Mach number, inlet velocities, turbulence intensities, inlet swirl, analytical and computational studies with respect to pressure recovery are fairly well established for two dimensional and conical diffusers and certain extent to annular diffusers. Pressure recovery coefficient increases with the diffuser passage for all values of inlet swirl up to 30°. Studies need to interlink the performance of diffusers with inlet conditions with other geometric and fluid dynamic parameters. Moreover, Experimental studies on annular diffuser complicated, time-consuming procedures and require sophisticated instrumentation which is not economically feasible and thus have limited the research activity in the field of annular diffusers. The computational studies which can produce results in close proximity with the experimental results need to be developed. The present state of research activity in the field of annular diffusers gives the direction to carry out the research work. The experimental work needs to be coupled with computational studies to explore and predict the flow development in the diffuser and predict its performance based upon the various inlet conditions.

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